Forms of Phosphorus in Soil Receiving Cattle Feedlot Waste[1]

A. N. SHARPLEY, S. J. SMITH, B. A. STEWART, AND A. C. MATHERS[2]

ABSTRACT

Cattle feedlot waste (FLW) was applied (176 to 1614 Mg ha^{-1}) to irrigated continuous-grain sorghum [*Sorghum bicolor* (L.) Moench] grown on Pullman clay loam (Torrertic Paleustolls) over an 8-y period. The FLW applications increased the total, inorganic, organic, and available P content and decreased the P sorption index of surface soil (0–30 cm). Amounts of P in the surface soil were highly correlated with the total amount of FLW-P applied and time since the last application. The proportion of total P as inorganic P increased (34 to 71%) with larger FLW applications. Increases in the amounts of surface soil inorganic and organic P with FLW application were due mainly to increases in labile fractions of these P forms. When FLW applications were stopped, however, soil organic P contents decreased to pretreatment levels more rapidly than inorganic P contents as a result of labile organic P mineralization. Increased P contents of surface soil following FLW applications will increase the potential for soluble and sediment-bound P to be transported in runoff.

Additional Index Words: **available P, inorganic P, organic P, total P, manure.**

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With the growth of cattle feedlots to above 50 000-head capacities, utilization of the manure on nearby cropland has received attention from soil fertility and environmental standpoints. Feedlot waste (FLW) application to cropland increases the plant nutrient content of surface soil (Abbott & Tucker, 1973; May & Martin, 1966; Meek et al., 1982; Smith et al., 1980) and yields of alfalfa (Goss & Stewart, 1979), sorghum (Mathers et al., 1975; Sukovaty et al., 1974), and corn (Vitosh et al., 1973). Large applications of FLW, however, can increase the nutrient content of both surface and subsurface runoff (Jones et al., 1975; McCalla et al., 1972; Muir et al., 1973).

While studies have investigated certain soil physical, chemical, and microbial changes associated with high rates of FLW application, little information exists on changes in amounts and distribution of P forms in the soil. This paper reports an investigation of the effect of several years of FLW application on the amounts and forms of P in soil cropped with grain sorghum [*Sorghum bicolor* (L.) Moench].

EXPERIMENTAL MATERIALS

Starting in 1969, FLW was applied to Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls), a major agricultural soil of the Southern High Plains (Table 1). Continuous grain sorghum was grown with moldboard plowing about 20 cm deep and furrow irrigation as necessary for optimum crop growth. The experimental plots (6 by 24 m) were in a randomized block with three replications. Virgin prairie and one commercial fertilizer treatment were included for comparison with the FLW application.

In April 1976, three 2.5-cm diameter soil cores were taken in 15-cm increments to a 90-cm depth from each plot and composited by treatment. The composited samples were ice-packed and shipped immediately to the USDA-ARS laboratory at Durant, Okla. On arrival, samples were air-dried, sieved (60-mesh), and stored in air-tight glass bottles.

EXPERIMENTAL METHODS

The total P (TP) and inorganic P (IP) contents of the soils were determined by extraction of ignited samples with 1.0*M* H_2SO_4 and nonignited samples with 0.5*M* H_2SO_4, respectively (Walker & Adams, 1958). Total organic P (OP) content was calculated as the difference between TP and IP. Plant-available P content was determined by the Bray-1 procedure, where 1 g of soil was extracted with 20 mL of 0.03*M* NH_4F and 0.025*M* HCl for 5 min (Bray & Kurtz, 1945). The extracts were centrifuged at 266 km s^{-2} (27 160 × *g*) for 5 min and filtered (0.45 μm).

The amount of P sorbed, X (μg g^{-1}), from one addition of 1.5 mg P per gram soil (added as K_2HPO_4) was determined after end-over-end shaking for 40 hr at a water/soil ratio of 100:1. The P sorption index was calculated using the quotient $X \log C^{-1}$, where C is solution P concentration (mg L^{-1}) (Bache & Williams, 1971). This quotient was highly correlated with P sorption maxima calculated from a Langmuir sorption plot for a wide range of soils (Bache & Williams, 1971).

Fractionation of soil IP into loosely-bound, nonoccluded, and occluded pools was carried out on surface samples (0–15 cm) by the procedure of Chang and Jackson (1957) as modified by Peterson and Corey (1966). Loosely-bound IP is represented by that extracted with 1.0*M* NH_4Cl, nonoccluded IP by 0.5*M* NH_4F, and 0.1*M* NaOH, and occluded IP by a second 0.1*M* NaOH extraction. The amount of soil OP in labile, moderately labile, moderately resistant (fulvic-acid P), and resistant (humic-acid P) pools was determined on surface samples (0–15 cm) by chemical extraction (Bowman & Cole, 1978).

A sample of FLW applied annually to the plots was collected each year and the TP content determined in a nitric, perchloric, and sulfuric acid digest (Mathers & Stewart, 1974). An additional FLW sample was collected in June 1982 and the IP and OP content and fractionation carried out by the above procedures.

For all samples the concentration of P was determined colorimetrically on filtered samples by the molybdenum-blue method (Murphy & Riley, 1962). Acid or alkali filtrates were neutralized prior to P determination.

In the following discussion, differences between treatments are significant at the 5% level as determined by analysis of variance, unless noted otherwise.

RESULTS AND DISCUSSION

The TP content of the FLW sample (8100 μg g^{-1}) collected in June 1982 for IP and OP fractionation was within the TP range of FLW added to the plots during the study (Table 2). For the June 1982 sample, 78% of the TP was inorganic (Table 2), as has been previously observed (Meek et al., 1975). Of the IP and OP in FLW, the major proportion was in labile fractions (54 and 80% as loosely-bound IP and labile and moderately labile OP, respectively).

Total, Inorganic, and Organic P

The content of P forms in surface soil (0–30 cm) generally increased with FLW application (Fig. 1, Table 3). All FLW treatments resulted in a greater TP, IP, and

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Table 1—Feedlot waste applications to Pullman clay loam at Bushland, Tex.

Code	Treatment	Rate	Years applied	TP applied†
		Mg ha⁻¹ per year		kg P ha⁻¹
VP	Virgin prairie	0		0
CHK	Check	0		0
NPK	NPK‡	56	1,2,3,4,5,6,7,8	450
22/8	FLW§	22	1,2,3,4,5,6,7,8	720
67/8	FLW	67	1,2,3,4,5,6,7,8	2180
538/1	FLW	538	1	1670
134/5	FLW	134	1,2,3,4,5	2090
269/5	FLW	269	1,2,3,4,5	4200
538/3	FLW	538	1,2,3	5650

† Calculated from the TP content (dry wt) of FLW applied each year.
‡ Applied as ammonium nitrate, conc superphosphate, and potassium chloride in spring. Rate for P is kg P ha⁻¹.
§ Feedlot waste applied in winter or spring (dry wt).

Table 2—P content of FLW applied to the plots.

P Fractionation	P Amount Total	P Amount Fraction
	μg P g⁻¹	
Total†	6900 (4890–9030)	
Inorganic‡		
Loosely bound		3430
Nonoccluded		2650
Occluded		260
Organic‡	1760	
Labile		430
Moderately labile		990
Moderately resistant		230
Resistant		110

† Average and (range) of TP content of FLW collected annually during the 8-y study.
‡ June 1982 sample.

OP content of surface soil than the check soil, except for treatments 22/8 and 538/1 for TP, 22/8 for IP, and 538/1 and 538/3 for OP (Table 3). Changes in OP content were less permanent than for IP, because the OP content of surface soil following the less frequent heavy FLW applications (538/1 and 538/3) returned to pretreatment levels (CHK), while IP remained elevated. The difference between IP and OP response is influenced by the fact that IP constituted the major form of FLW–TP (78%). This also resulted in an increase in the proportion of TP present in the inorganic form in surface soil from 34 (CHK) to 71% (538/3) with increasing FLW application (Table 3).

No difference in TP, IP, or OP contents of surface or profile soil was observed when a greater amount of P was added in FLW (720 kg TP ha⁻¹, 22/8) than in mineral fertilizer (450 kg TP ha⁻¹, NPK) (Table 3). This

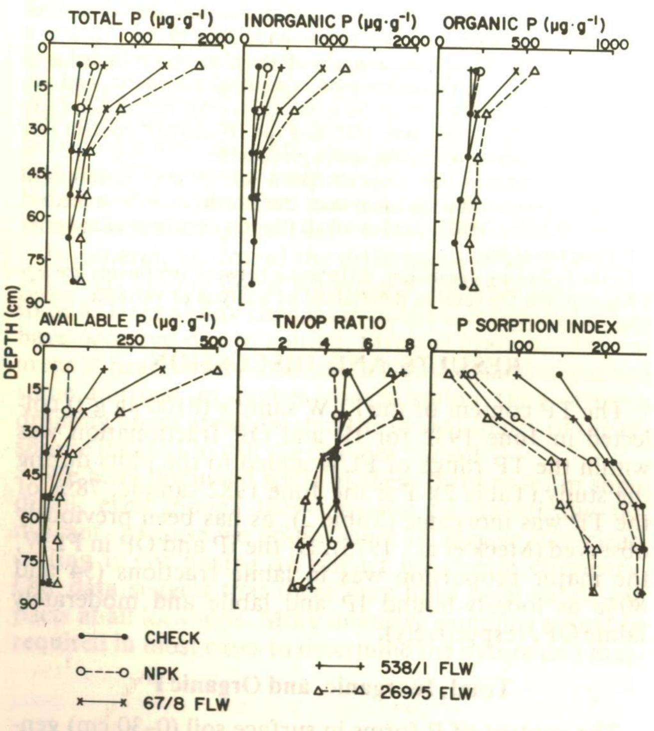

Fig. 1—Distribution of total, inorganic, organic, and available P, P sorption index, and total N/organic P ratio with depth in Pullman clay loam amended with FLW.

suggests that FLW is more available for crop uptake and is more susceptible to leaching than mineral fertilizer P. Leaching was not considered important, however, as little change in P content was observed below the 75-cm depth (Fig. 1).

The TP and IP content of surface soil for the continuous application treatment of 67/8 was greater than that for the 538/1 and 134/5 treatments (Table 3), even though similar amounts of P were applied (Table 1). Similarly, OP contents for the frequent application treatments (67/8 and 269/5) were higher than the other treatments (Table 3). Consequently, uptake of IP by the grain sorghum crop and mineralization of OP added in the FLW, occurred during the years following cessation of FLW application. The importance of FLW application frequency on the amounts of P in surface soil is apparent from the fact that no significant relationship was obtained between P content of soil and amount of P added in FLW. When time since the last FLW application was included in the regression with P added (multiple regression), a highly significant (at 0.1% level) relationship for both TP (R^2 = 0.81) and IP (R^2 = 0.84) was obtained. For OP, no significant correlation was obtained, indicating that OP levels are also controlled by other variables, such as soil temperature and moisture.

Available P and P Sorption Index

All FLW treatments resulted in an increase in the available P content of surface soil compared with the check, with the proportion of TP as available increasing from 4% (CHK) to 29% (269/5) (Table 3). Little change in available P content was observed below the 50-cm depth (Fig. 1). In contrast, Campbell and Racz (1975) observed that FLW application increased available P contents to a soil depth of 120 to 150 cm. The greater mobility of FLW–P may be attributed to the fact that FLW was applied to a sandy soil, whereas the present study was carried out on a clay loam.

A decrease in P sorption index with increasing FLW application was obtained (Fig. 1, Table 3) and attributed to the sorption of FLW–P by soil material reducing the number of unsatisfied P sorption sites. A general increase in the total N/organic P ratio of surface

Table 3—Distribution of P forms in Pullman clay loam.

Parameter	Soil layer‡	Treatments†								
		VP	CHK	NPK	22/8	67/8	538/1	134/5	269/5	538/3
Total P ($\mu g\ g^{-1}$)	Surface	399a	353a	457a	538ab	996c	553ab	696db	1278e	824cd
	Profile	328a	312a	350a	402ab	581ce	396ab	490bc	706e	499bc
Inorganic P ($\mu g\ g^{-1}$)	Surface	136a	151a	226ab	256ab	673c	352bd	421d	872e	588c
	Profile	140a	141a	171ab	193ab	356cd	223abc	262abc	425d	316bcd
Organic P ($\mu g\ g^{-1}$)	Surface	264ab	202a	231ab	283bc	323c	201a	275bc	406d	236ab
	Profile	188abc	171ab	179ab	209bc	225c	171ab	229c	281d	183ab
Available P§ ($\mu g\ g^{-1}$)	Surface	16a	15a	56b	63b	230c	120d	135d	370e	193c
	Profile	9a	8a	24ab	28ad	88c	55d	57d	149e	102c
P Sorption index	Surface	171a	165a	74b	120cd	78b	132c	105d	47e	109d
	Profile	218a	215a	175b	200c	141de	201c	155d	128e	184c
TN/OP¶	Surface	4.7abc	5.0abc	4.6ab	4.2a	5.8abc	6.4abc	5.8abc	7.3bc	7.6c
	Profile	4.3a	4.7a	4.3a	4.0a	4.5a	4.8a	4.3a	4.6a	5.5a

† Within-row values followed by the same letter are not statistically different (5% level).
‡ Surface and profile represent 0- to 30-cm and 0- to 90-cm depths, respectively.
§ Bray-1 available P.
¶ Total N/organic P ratio.

soil was observed with increasing FLW application, although the increases were not significant. This may be expected as the total N/organic P ratio of FLW (9.0) was greater than that of the check surface soil (4.7). A similar increase in total N/organic P ratio of an alkaline sandy soil following FLW application has been observed (Campbell & Racz, 1975).

The application of P as FLW had a smaller effect on both available P content and P sorption index of surface soil compared with application as mineral fertilizer (NPK). For available P, the twofold greater P application of 22/8 than NPK (Table 1) resulted in no difference in amounts of available P in the respective surface soils. This was even more dramatic for the P sorption index, with only the 269/5 treatment yielding a lower sorption value than the NPK treatment (Table 3). The relatively smaller effect of FLW than mineral fertilizer on the P sorption index may result from the fact that only a portion of inorganic P added with FLW (54%, Table 2) could be readily sorbed, whereas 100% of the mineral fertilizer P is initially sorbable. Furthermore, formation of organic complexes by the addition of organic matter in FLW may sorb some of the added IP (Harter, 1969; Saini & McLean, 1965; Williams, 1960), thereby not reducing the surface soil P sorption index as measured at the end of the study period. This is in agreement with Goss and Stewart (1979), who found that FLW-P had a greater residual plant availability due to a lower initial availability of FLW-P, reducing luxury consumption by the crop, a slower release of P from FLW by microbial activity, and a reduced sorption of FLW-P than for superphosphate.

As was the case for TP and IP, frequent FLW applications had a greater effect on both available P content and P sorption index of the surface soil than less frequent applications, even though smaller amounts of P were applied in the former treatments (Table 3). In addition, available P content (R^2 = 0.77, 0.1% level) and P sorption index (R^2 = 0.66, 1.0% level) of surface soil were related to the amount of P added and time following the last FLW application. Like TP, IP, and OP, cropping with no P addition (CHK) had no significant effect on available P content, P sorption index, or total N/organic P ratio compared with the virgin soil (VP) during the study period (Table 3).

In earlier studies on the same Pullman clay loam plots, Mathers et al. (1975) and Mathers and Stewart (1983) found that the 22/8 FLW treatment produced maximum grain sorghum yields. In the years that the 269 and 538 Mg FLW ha^{-1} per year rates were applied, however, grain sorghum yields were decreased as a result of higher ammonia and salt concentrations in the root zone. When these treatments were discontinued, grain sorghum yield increased; 2 yr after the last FLW application, grain sorghum yields were similar to those of the highest yielding treatment (22/8). Similar results were reported by Vitosh et al. (1973) and Wallingford et al. (1975).

P Fractionation

INORGANIC

Amounts of IP in all fractions increased as a result of FLW application (Fig. 2). The proportion of IP in loosely-bound and nonoccluded fractions increased for all FLW treatments compared with the check, while that in the occluded fraction decreased. Different FLW applications, however, had little effect on the proportion of IP in each fraction (Fig. 2).

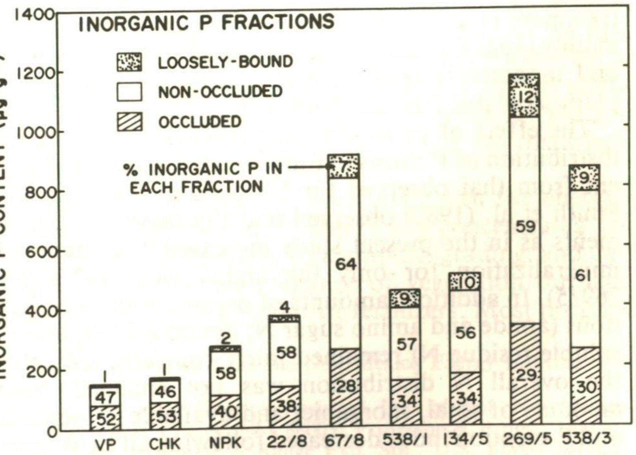

Fig. 2—Distribution of inorganic P in loosely-bound, nonoccluded, and occluded fractions of Pullman clay loam (0- to 15-cm depth) amended with FLW.

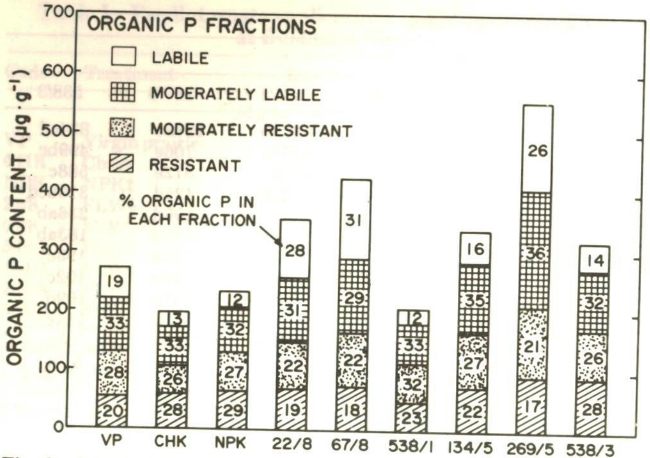

Fig. 3—Distribution of organic P in labile, moderately labile, moderately resistant, and resistant fractions of Pullman clay loam (0- to 15-cm depth) amended with FLW.

ORGANIC

The sum of the OP content of the four fractions directly measured by the procedure of Bowman and Cole (1978) was very close to the total amount measured by difference using the ignition method (data not presented) (Walker & Adams, 1958). For all the treatments a regression of the two methods had a slope of 0.96 and a R^2 of 0.996 (0.1% level), supporting the use of both methods for OP measurement.

A general increase in the amounts of OP in each fraction occurred with all FLW applications except 538/1 compared with the check; however, the proportion of OP in moderately labile, moderately resistant, and resistant fractions was affected little by rate of FLW application (Fig. 3). As was the case for IP, the magnitude of change in amounts of OP in each fraction following FLW application compared with the check was greatest for the more labile fractions (Fig. 3).

Cultivation of the soil with no P applied as FLW or mineral fertilizer (CHK) resulted in a decrease in the content of all OP fractions compared with the VP except resistant OP, which remained constant (57 and 54 $\mu g\ g^{-1}$ for CHK and VP, respectively). Since little change was observed in the IP content of the check treatment (Fig. 2), it is possible that mineralization of mainly labile OP and to a lesser extent moderately labile and moderately resistant OP replenished the pool of plant-available P in the check soil.

The effect of FLW application on the amounts and distribution of P forms in Pullman clay loam was different from that observed for N forms in the same soil. Smith et al. (1980) observed that the same FLW treatments as in the present study increased N content and mineralization for only the higher rates (67/8 and 269/5). In addition, amounts of organic N in three fractions (amide and amino sugar N; amino acid N; and insoluble residue N) remained fairly constant, indicating the overall N distribution was not changed. Since amounts of total, inorganic, and available P increased and P sorption index decreased following all FLW treatments and IP and OP fractions were redistributed, it is evident that FLW will affect the amounts and forms of soil P to a greater extent than soil N.

SUMMARY

The amounts and distribution of P forms in a clay loam under irrigated grain sorghum were measured following FLW application to determine what effects continuous and/or large applications can have on soil P chemistry. Although FLW is regarded as an organic amendment, IP constituted the major proportion (78%) of FLW–P. Consequently, FLW application increased the proportion of TP as IP (34 to 71%) in the surface soil. The increases in both IP and OP were due mainly to incorporation of FLW–P into labile soil P fractions. However, mineralization of labile OP resulted in a more rapid return to pretreatment levels for OP than IP. Feedlot waste increased the proportion of TP as Bray 1 available P in surface soil from 4% for the check to 30% for the continuous, larger applications. As little movement of inorganic, organic, or available P was observed through the soil profile, it is suggested that in the present study, FLW application presented little threat to the contamination of groundwater with P, although the transport of both soluble and TP in surface runoff may increase. Furthermore, the decrease in the P sorption index with FLW application will increase the susceptibility of future P applications to removal in runoff. However, these adverse soil P effects that may occur at the higher FLW application rates can be eliminated by changing the cultural practice and/or discontinuing the FLW applications.

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Responses of Soil Biota to Organic Amendments in Stripmine Spoils in Northwestern New Mexico[1]

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ABSTRACT

We examined the effects of organic amendments and topsoiling on the soil biota and decomposition in order to evaluate the relative efficacy of the amendments in restarting soil processes. We studied decomposition of barley straw (*Hordeum vulgare*) and populations of soil biota on strip coal-mine spoils in northwestern New Mexico. The spoils had been amended with straw mulch, bark, topsoil, or no organic additives. Decomposition rates were highest in the unmined area and the bark, amended spoils (K = 0.64 yr^{-1}) (K = first-order rate constant), and lowest on the topsoil amendment and unamended spoil (K = 0.34 yr^{-1}). Few differences were observed in the populations of soil microflora. Where differences were observed, the bark-amended spoils had the highest populations and biomass. Soil microflora activity, as indicated by decomposition rates, was enhanced by bark amendment. Soil microfaunal populations were highest on the bark-amended spoils and unmined soil. Important soil mites (soil Acari), the oribatids, were found only in the bark-amended spoils and the unmined soils. These studies suggest that addition of selected organic amendments (bark) to mine spoils may be as effective in developing a soil as the more expensive topsoil/mulch procedures currently used in reclamation procedures.

Additional Index Words: **reclamation, microarthropods, decomposition, soil microflora, organic amendments.**

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Ecosystem level research has focused on two general paradigms in the attempts to understand the complex linkages and feedbacks of such systems: (i) energy flow and (ii) nutrient (material) cycling. Energy flow models of ecosystems that focus on aboveground production, consumer, predator, and decomposer trophic relationships have limited utility in providing insights into results of ecosystem perturbation. Nutrient cycling models have the advantage of providing such insights. A key process in nutrient cycling is the decomposition of dead plant material. Studies in forest ecosystems have documented the vital role of detritus (litter) and soil-dwelling organisms in that process (Crossley, 1977; McBrayer, 1977). Several recent studies have addressed the activities of microflora and population responses of selected soil fauna in disturbed systems such as surface mine sites and agricultural tillage (Stroo & Jencks, 1982; Fresquez & Lindemann, 1982; Loring et al., 1981). However, neither these studies nor earlier studies measured the responses of the soil biota (microarthropods, nematodes, protozoans, fungi, and bacteria) simultaneously. Since these organisms are interdependent, we feel it is important to examine all soil biotic components when assessing the efficacy of a reclamation or cultivation practice. However, there have been no studies of which we are aware, that address the importance of the total soil biota in disturbed systems such as cultivated croplands, surface mine sites, etc. In addition, virtually no emphasis has been given to the reestablishment of a complete soil biota on disturbed lands that require reclamation.

Reclamation procedures associated with the energy-producing industries have historically concentrated on erosion control through topographic grading and reestablishment and maintenance of vegetation through repeated post-seeding inputs of fertilizers. Most promis-

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